FIG. 1

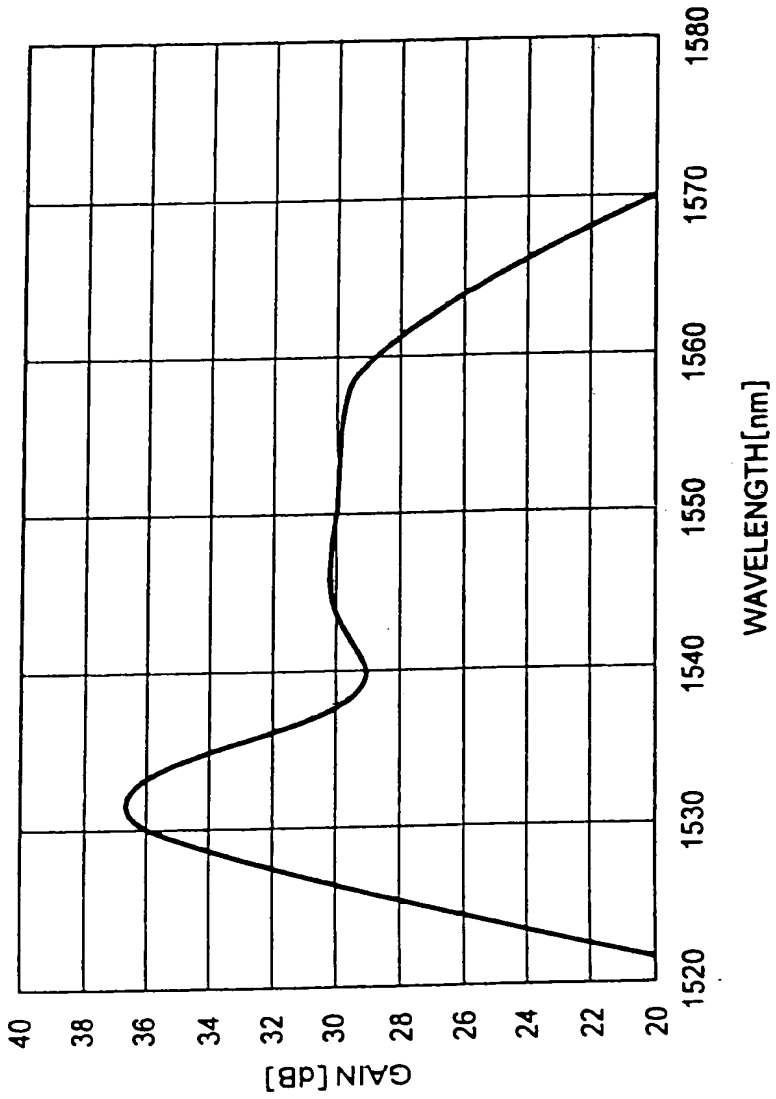

GAIN [dB]
40
38
36
34
32
30
28
26
24
22
20
WAVELENGTH[nm]
1520
1530
1540
1550
1560
1570
1580

FIG. 2

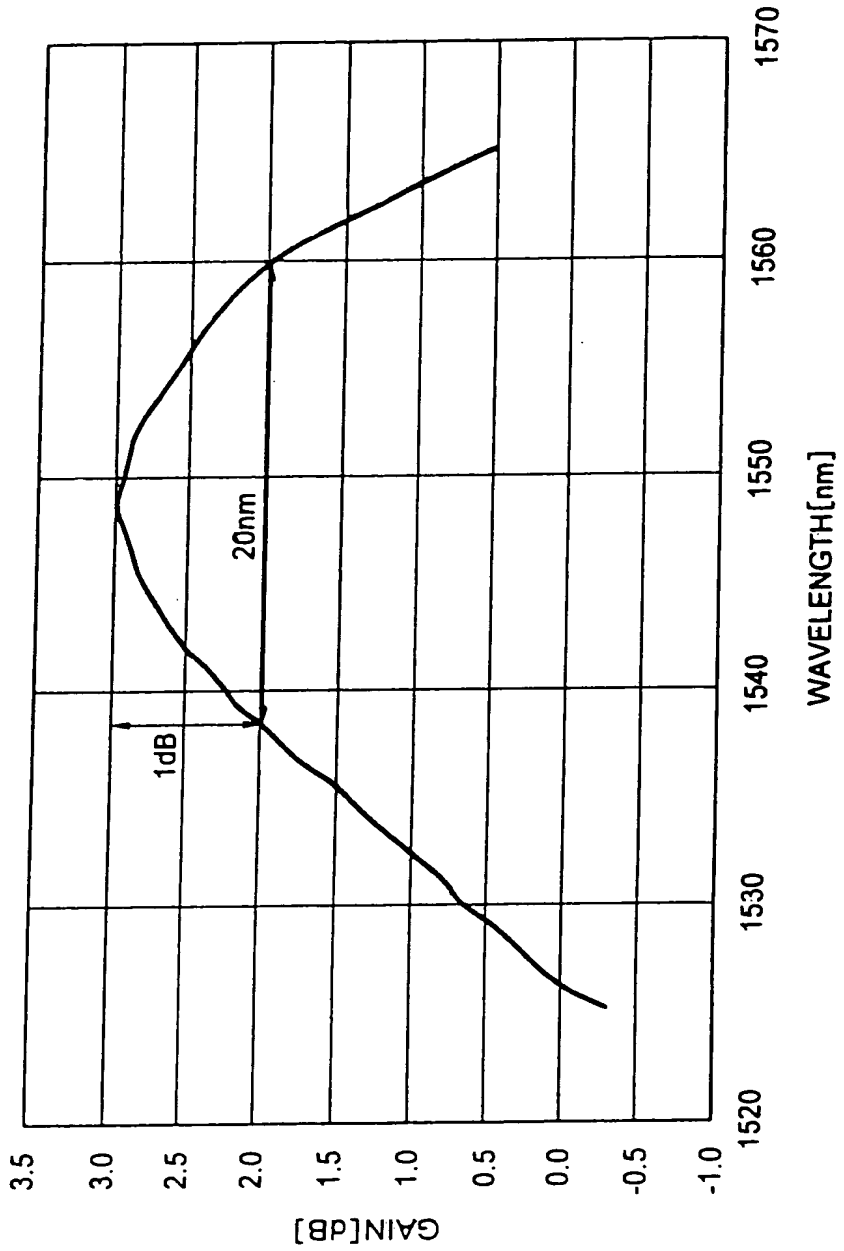

GAIN[dB]
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1dB
20nm
1520
1530
1540
1550
1560
1570
WAVELENGTH[nm]

FIG. 3

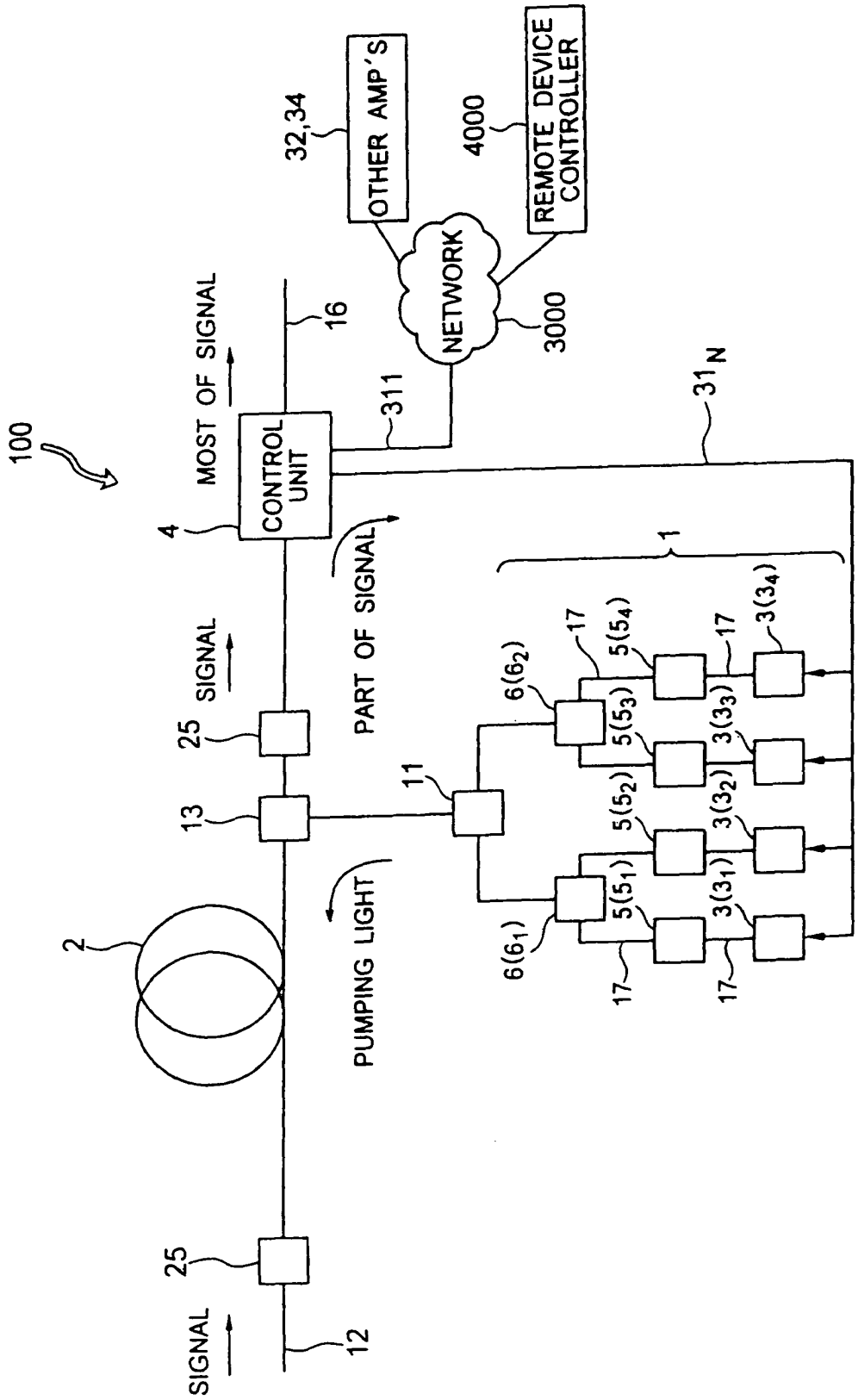

100
MOST OF SIGNAL
CONTROL UNIT
4
16
311
NETWORK
3000
OTHER AMP'S
32,34
REMOTE DEVICE CONTROLLER
4000
31N
1
PART OF SIGNAL
SIGNAL
25
13
11
2
PUMPING LIGHT
SIGNAL
25
12
6(6₂)
6(6₁)
5(5₄)
5(5₃)
5(5₂)
5(5₁)
3(3₄)
3(3₃)
3(3₂)
3(3₁)
17

FIG. 4

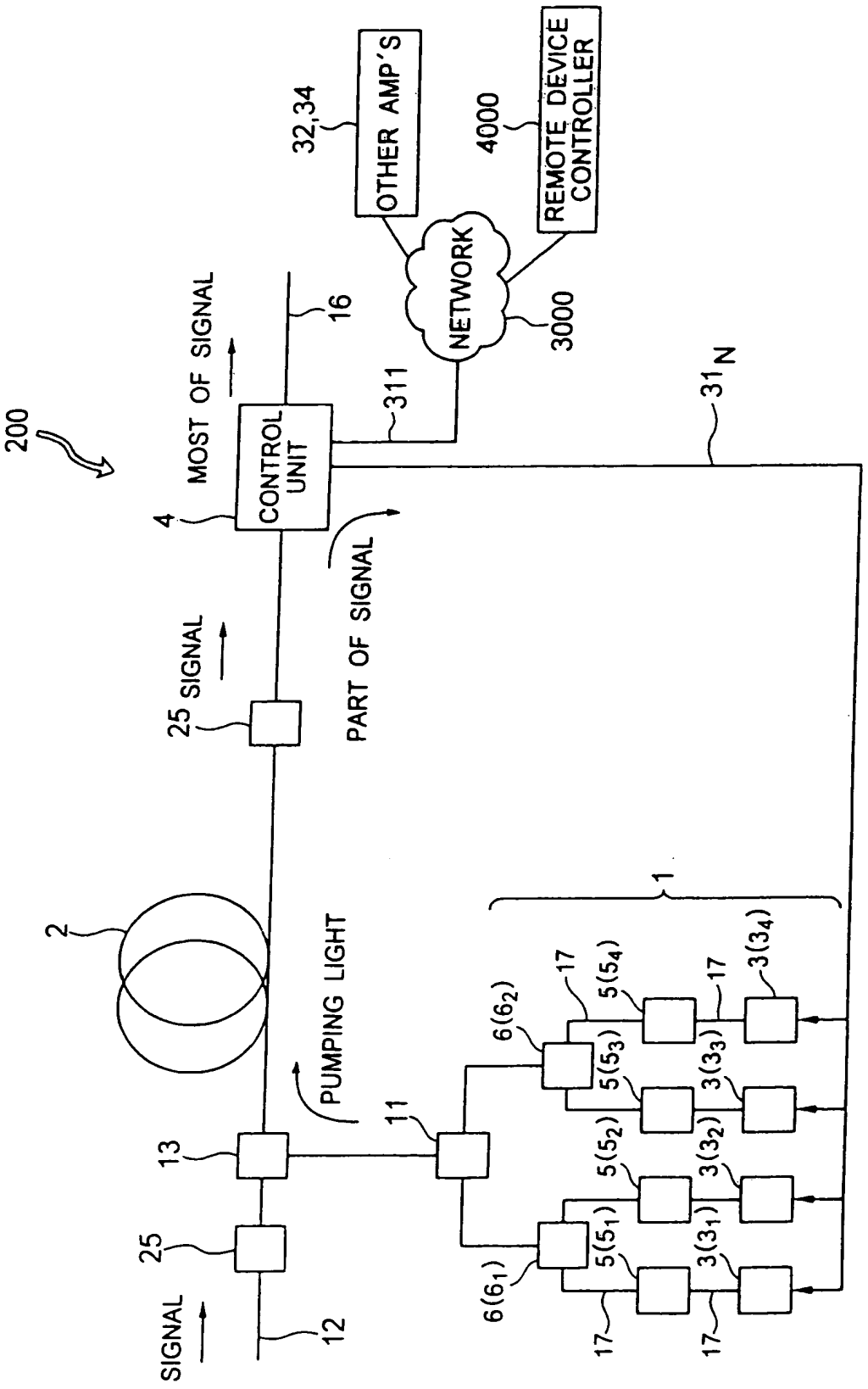

200
MOST OF SIGNAL
CONTROL UNIT
4
16
311
NETWORK
3000
32,34
OTHER AMP'S
4000
REMOTE DEVICE CONTROLLER
31N
25
SIGNAL
PART OF SIGNAL
2
PUMPING LIGHT
13
11
1
25
SIGNAL
12
6(6₂)
6(6₁)
17
5(5₄)
5(5₃)
5(5₂)
5(5₁)
3(3₄)
3(3₃)
3(3₂)
3(3₁)

FIG. 5

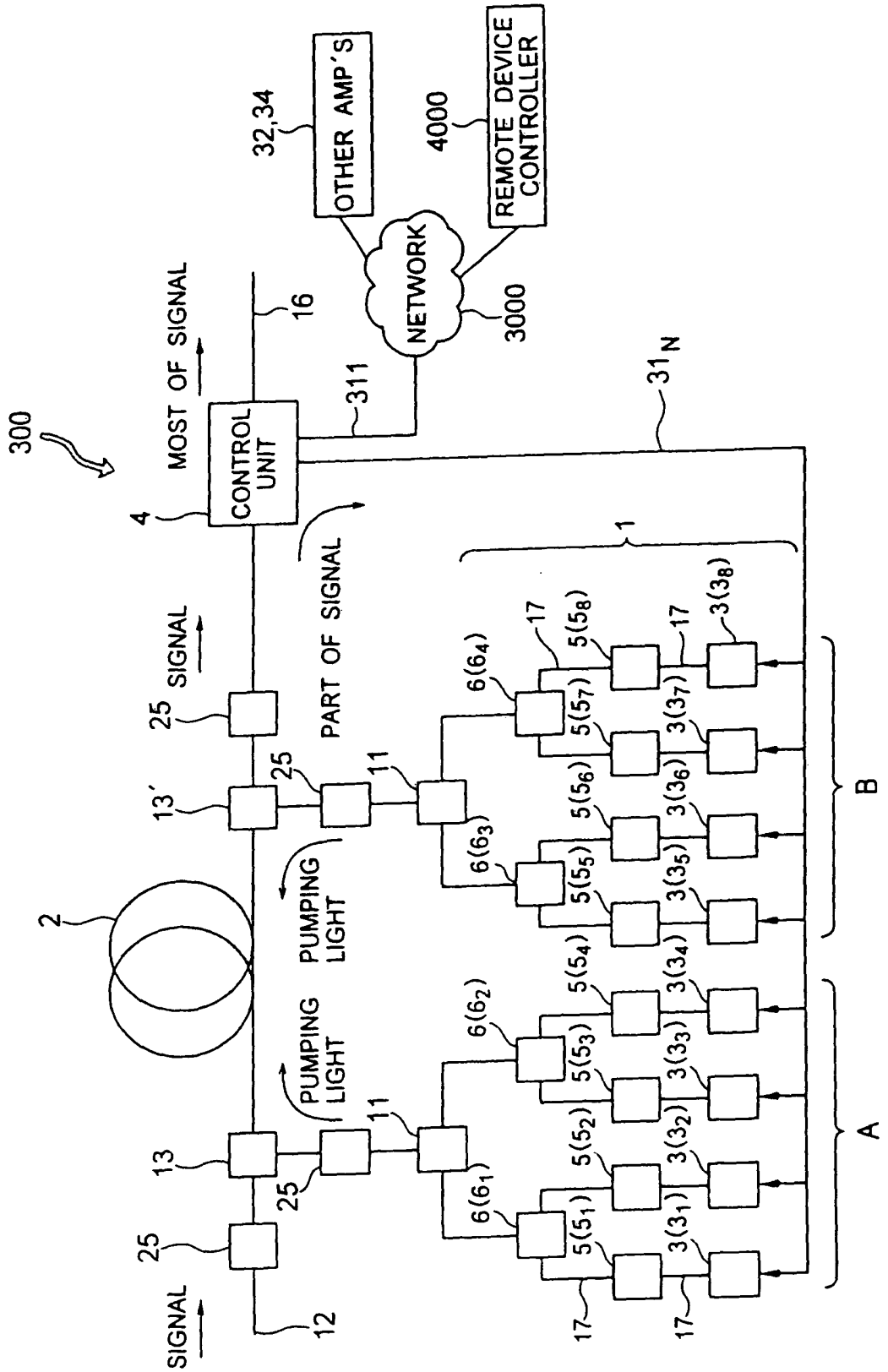

300
MOST OF SIGNAL
CONTROL UNIT
4
16
311
NETWORK
3000
32,34
OTHER AMP'S
4000
REMOTE DEVICE CONTROLLER
31N
1
PART OF SIGNAL
SIGNAL
25
13'
11
2
PUMPING LIGHT
PUMPING LIGHT
13
12
17
B
A
6(6₄)
6(6₃)
6(6₂)
6(6₁)
5(5₈)
5(5₇)
5(5₆)
5(5₅)
5(5₄)
5(5₃)
5(5₂)
5(5₁)
3(3₈)
3(3₇)
3(3₆)
3(3₅)
3(3₄)
3(3₃)
3(3₂)
3(3₁)

FIG.6

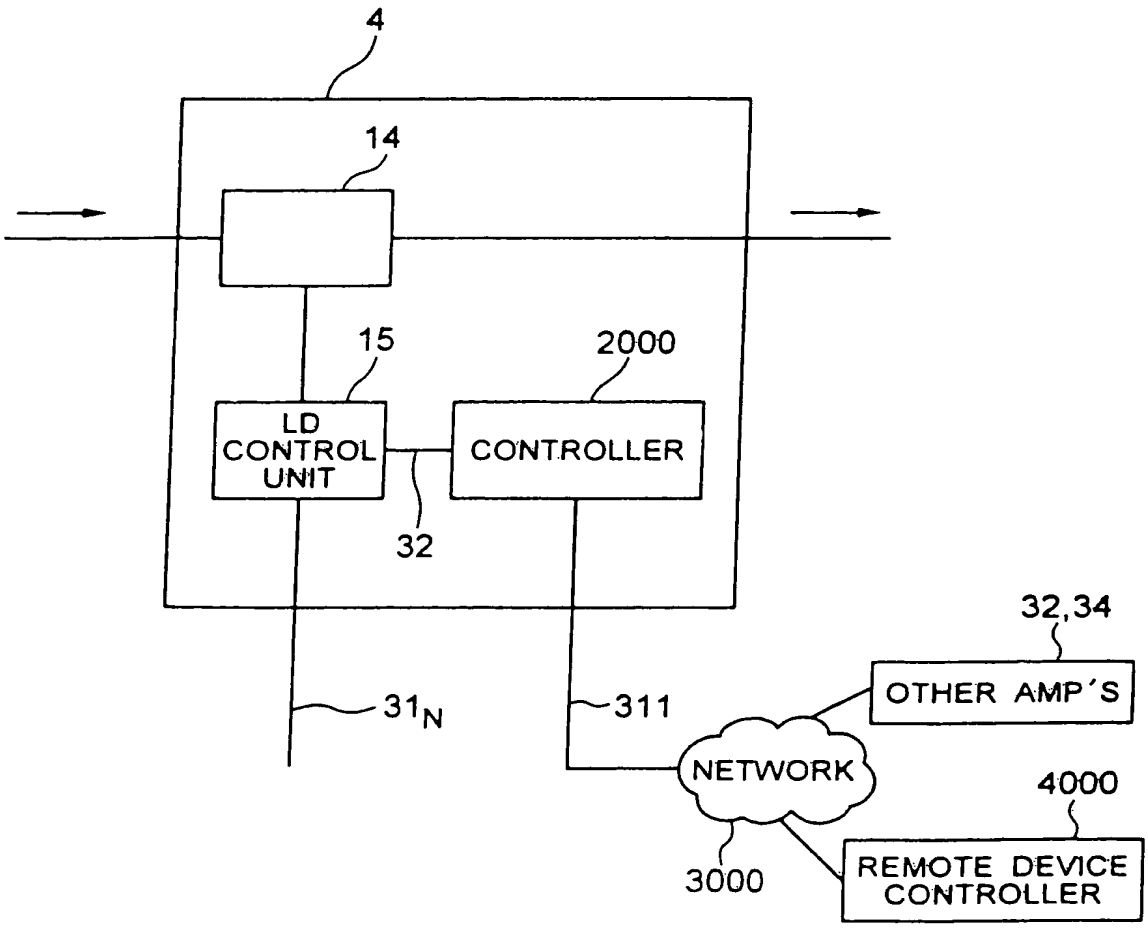

4
14
15
2000
LD CONTROL UNIT
CONTROLLER
32
32,34
OTHER AMP'S
31_N
311
NETWORK
4000
3000
REMOTE DEVICE CONTROLLER

FIG.7

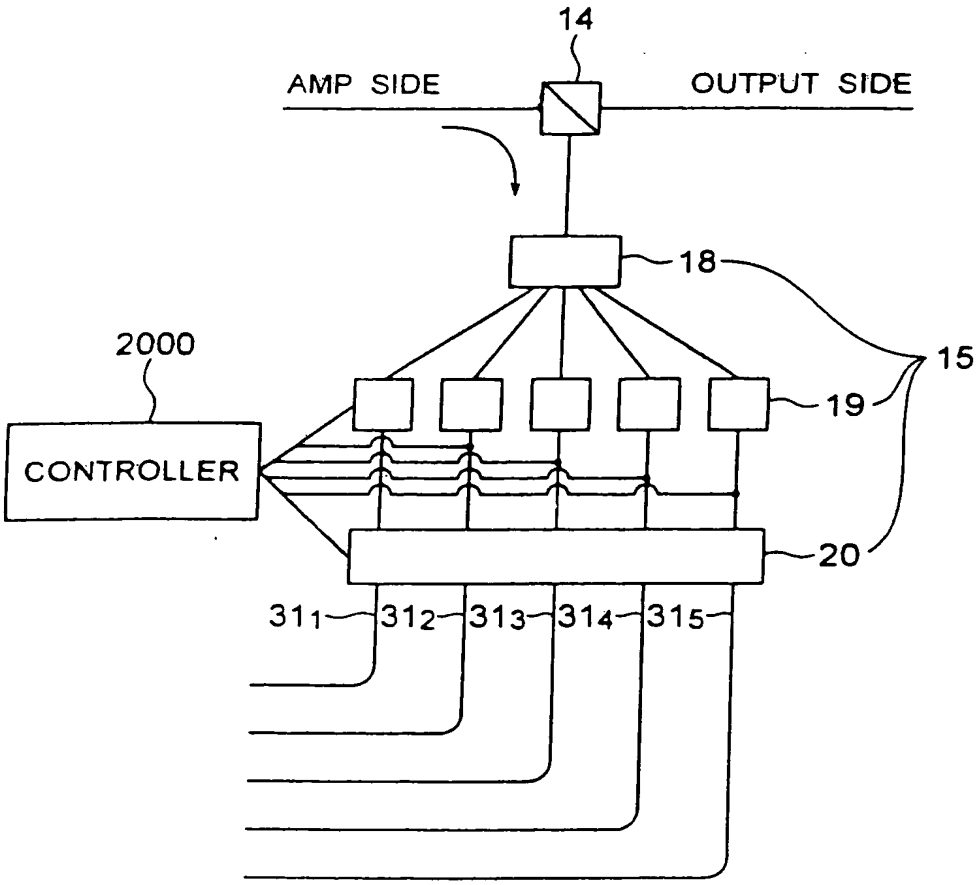

14
AMP SIDE
OUTPUT SIDE
18
2000
15
19
CONTROLLER
20
311
312
313
314
315

FIG.8

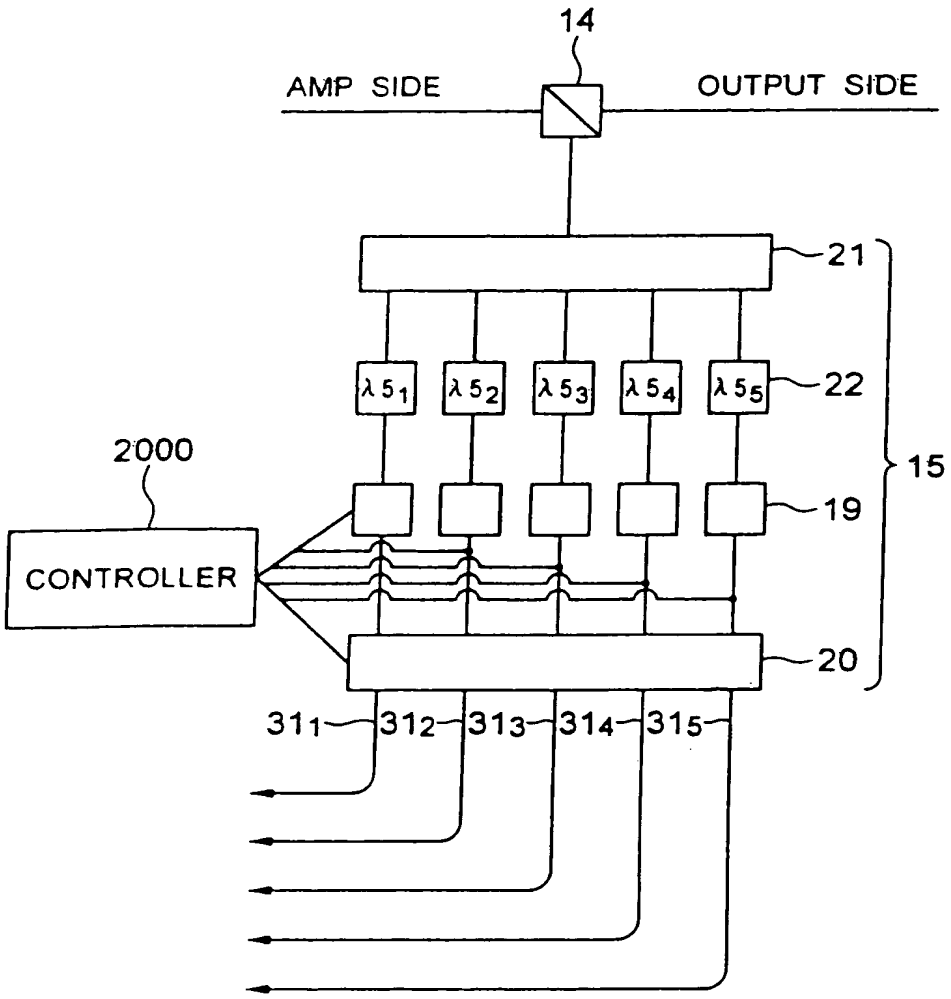

14
AMP SIDE
OUTPUT SIDE
21
λ5₁
λ5₂
λ5₃
λ5₄
λ5₅
22
2000
15
19
CONTROLLER
20
311
312
313
314
315

FIG.9

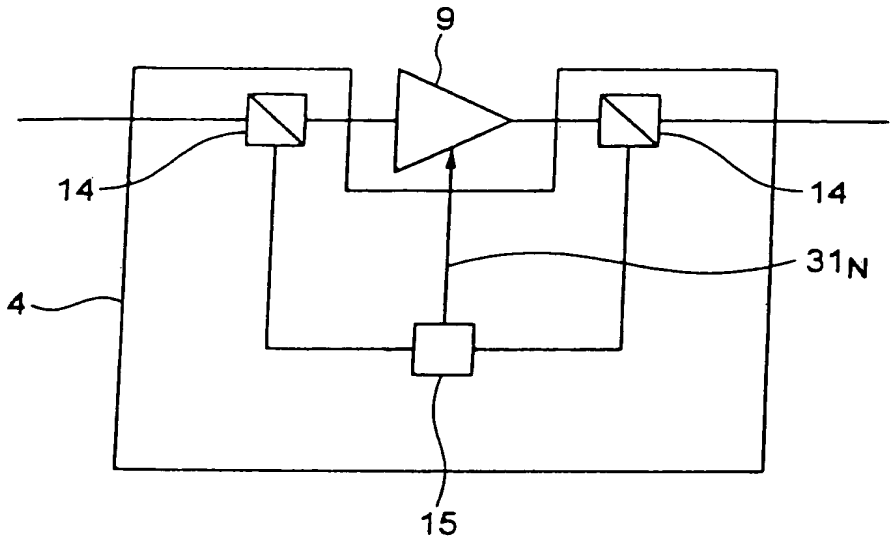


FIG. 10

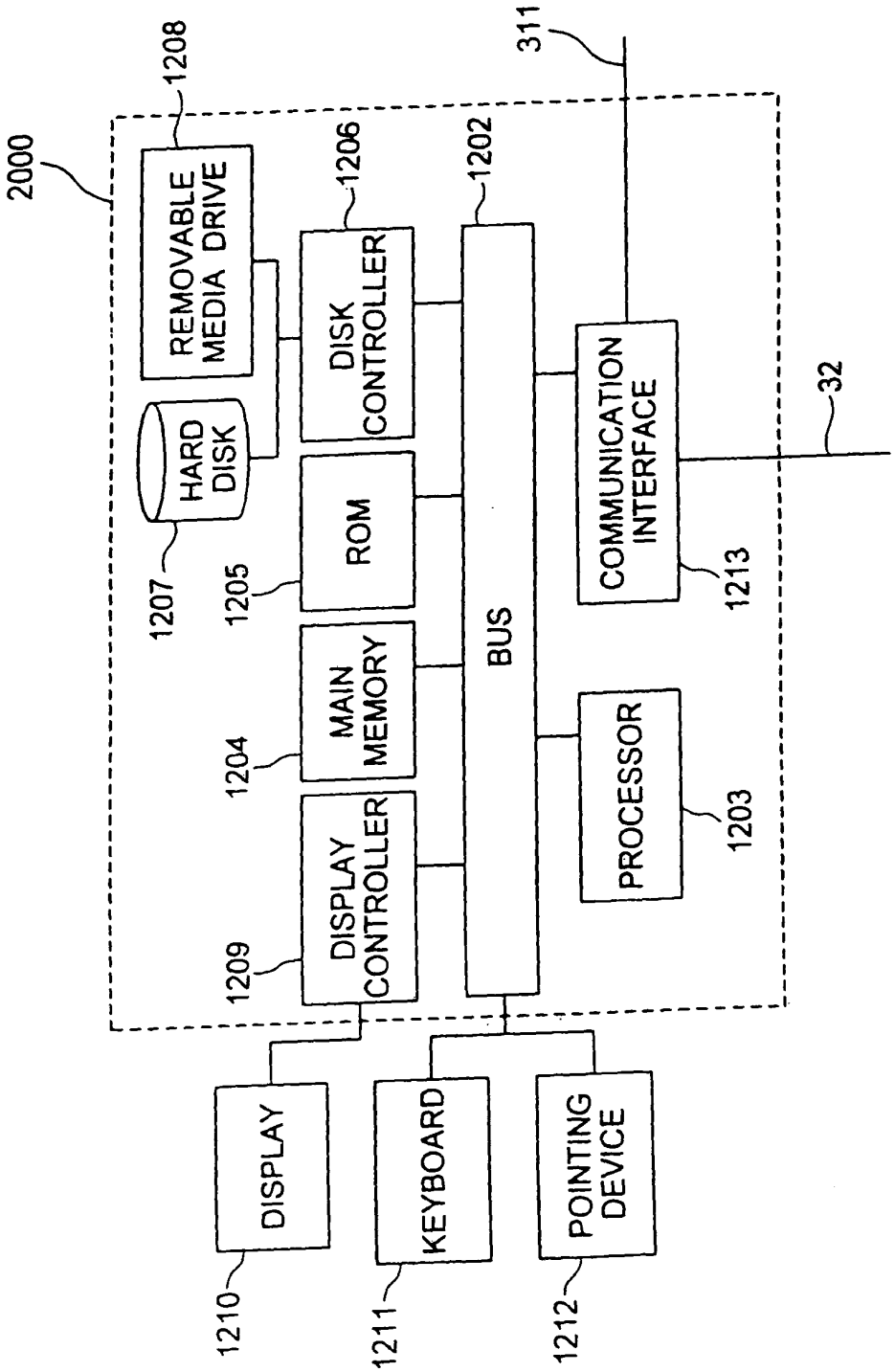

2000
1208
REMOVABLE MEDIA DRIVE
HARD DISK
1207
1206
DISK CONTROLLER
1205
ROM
1204
MAIN MEMORY
1209
DISPLAY CONTROLLER
1202
BUS
311
COMMUNICATION INTERFACE
1213
32
PROCESSOR
1203
DISPLAY
1210
KEYBOARD
1211
POINTING DEVICE
1212

FIG.11

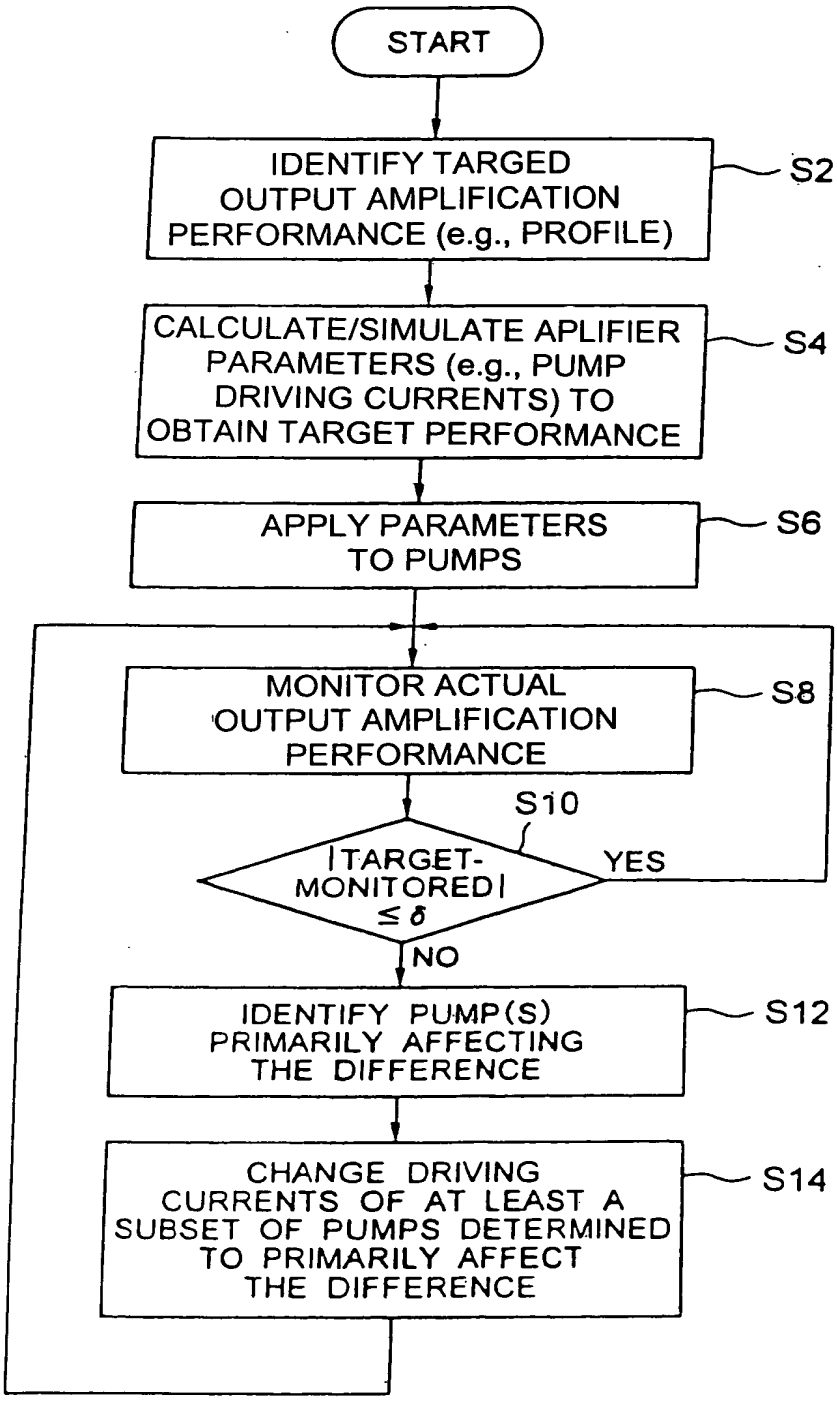

START
IDENTIFY TARGED OUTPUT AMPLIFICATION PERFORMANCE (e.g., PROFILE)
S2
CALCULATE/SIMULATE APLIFIER PARAMETERS (e.g., PUMP DRIVING CURRENTS) TO OBTAIN TARGET PERFORMANCE
S4
APPLY PARAMETERS TO PUMPS
S6
MONITOR ACTUAL OUTPUT AMPLIFICATION PERFORMANCE
S8
S10
|TARGET-MONITORED| ≤ δ
YES
NO
IDENTIFY PUMP(S) PRIMARILY AFFECTING THE DIFFERENCE
S12
CHANGE DRIVING CURRENTS OF AT LEAST A SUBSET OF PUMPS DETERMINED TO PRIMARILY AFFECT THE DIFFERENCE
S14

FIG. 12

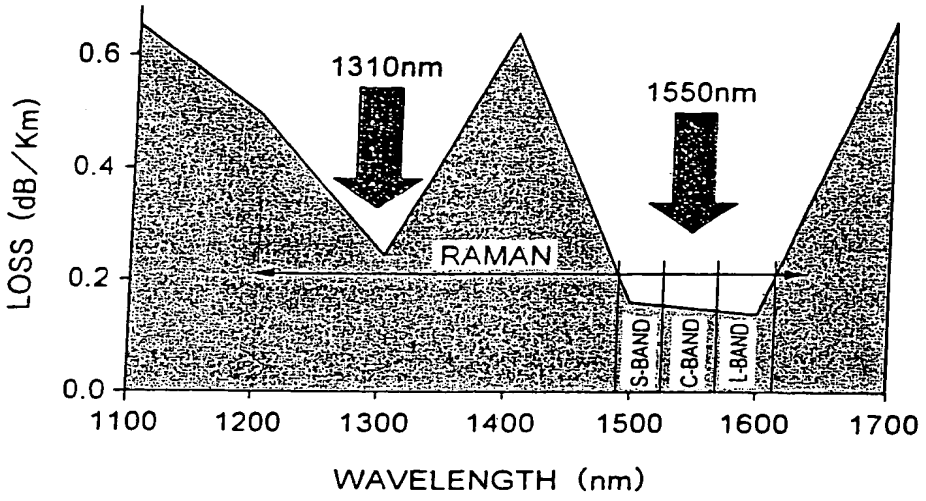


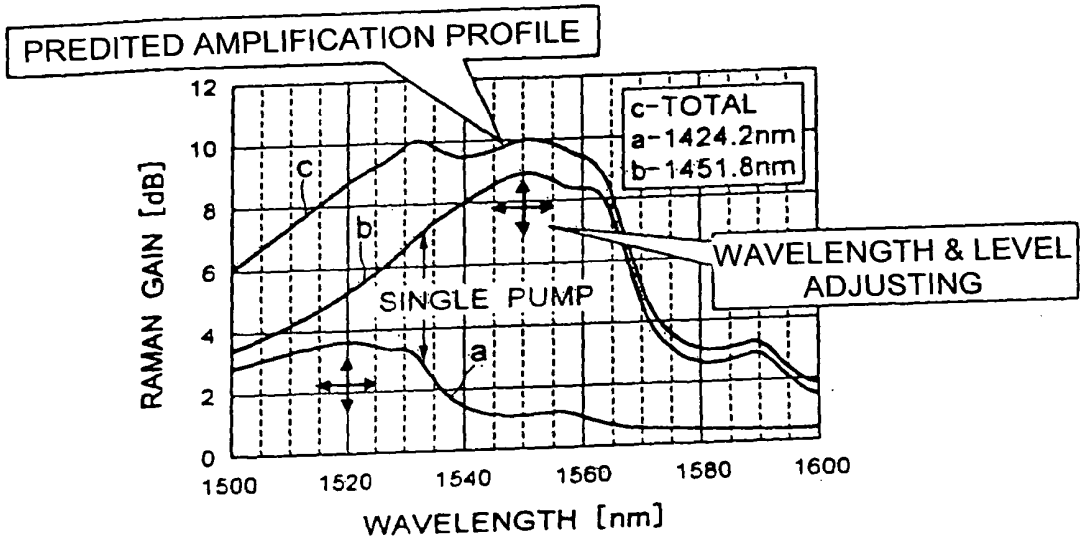
FIG. 13

WAVELENGTHS (nm)

	1100	1200	1300	1400	1500	1600	1700
DRIVING CURRENTS (mA)	560	250	120	560	100	90	560

FIG. 14

SUPERPOSITION PRINCIPLE

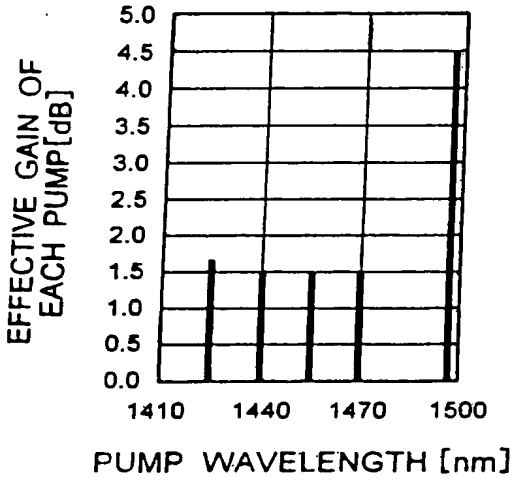


DESIGN OF PUMPING WAVELENGTH
BASED ON SUPERPOSITION PRINCIPLE

DESIGN PARAMETERS:

WAVELENGTH ALLOCATION
EFFECTIVE GAIN ALLOCATION

FIG. 15A



SPECIFICATIONS:

FIBER TYPE, GAIN AND FLATNESS
BANDWIDTH, NUMBER OF LDS

FIG. 15B

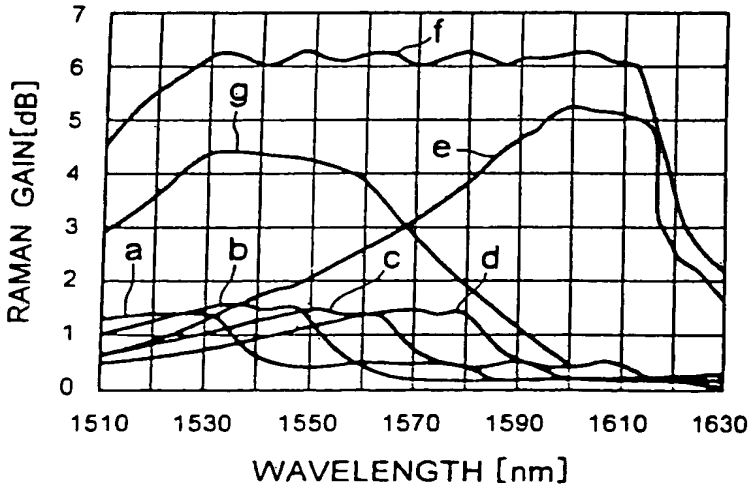
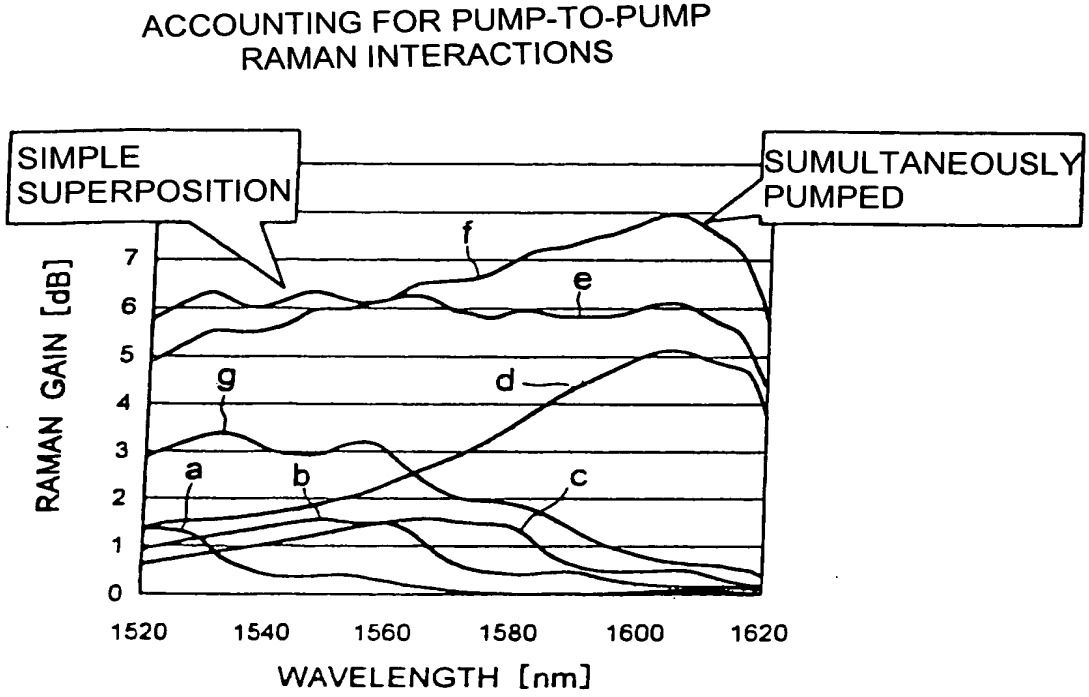


FIG. 16



(a) 1420 nm PUMP

(b) 1435 nm PUMP

(c) 1450 nm PUMP

(d) 1495 nm PUMP (ALSO ELEMENT GAIN FOR PUMP AT LONGER WAVELENGTH)

(e) TOTAL GAIN IF NO PUMP-TO-PUMP INTERACTION

(f) TOTAL GAIN, INCLUDING PUMP-TO-PUMP INTERACTION

(g) ELEMENT GAIN FOR 3 PUMPS AT SHORTER WAVELENGTHS

FIG. 17

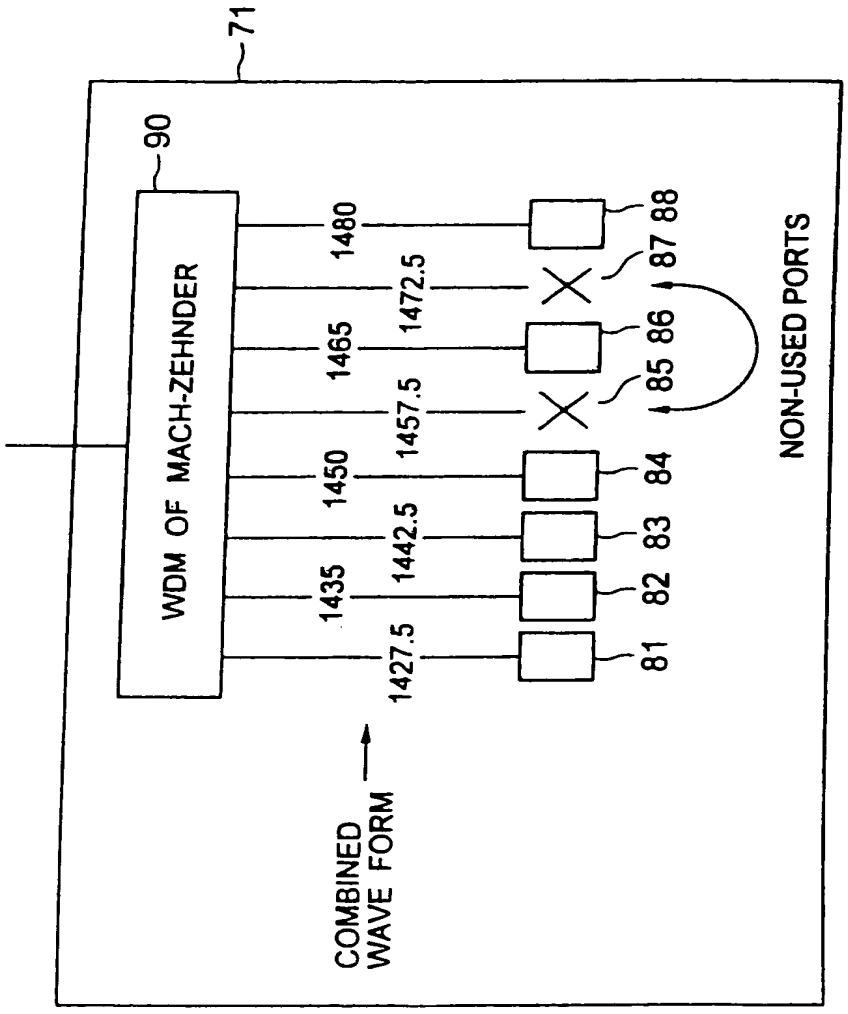

71
90
WDM OF MACH-ZEHNDER
1480
1472.5
1465
1457.5
1450
1442.5
1435
1427.5
87 88
85 86
84
83
82
81
NON-USED PORTS
COMBINED WAVE FORM

FIG. 18

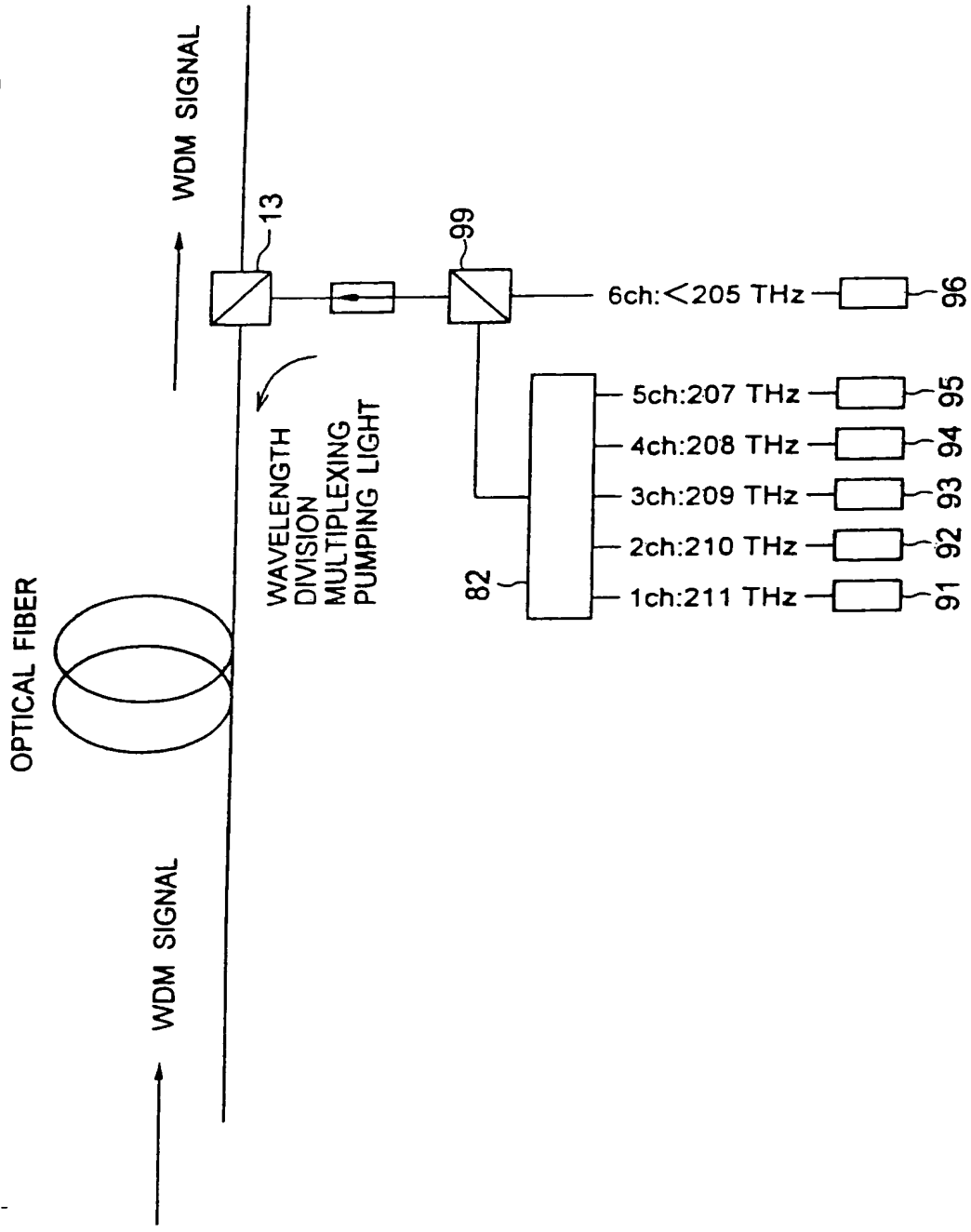

WDM SIGNAL
13
99
6ch:<205 THz
96
5ch:207 THz
95
4ch:208 THz
94
3ch:209 THz
93
2ch:210 THz
92
1ch:211 THz
91
82
WAVELENGTH DIVISION MULTIPLEXING PUMPING LIGHT
OPTICAL FIBER
WDM SIGNAL

FIG. 19

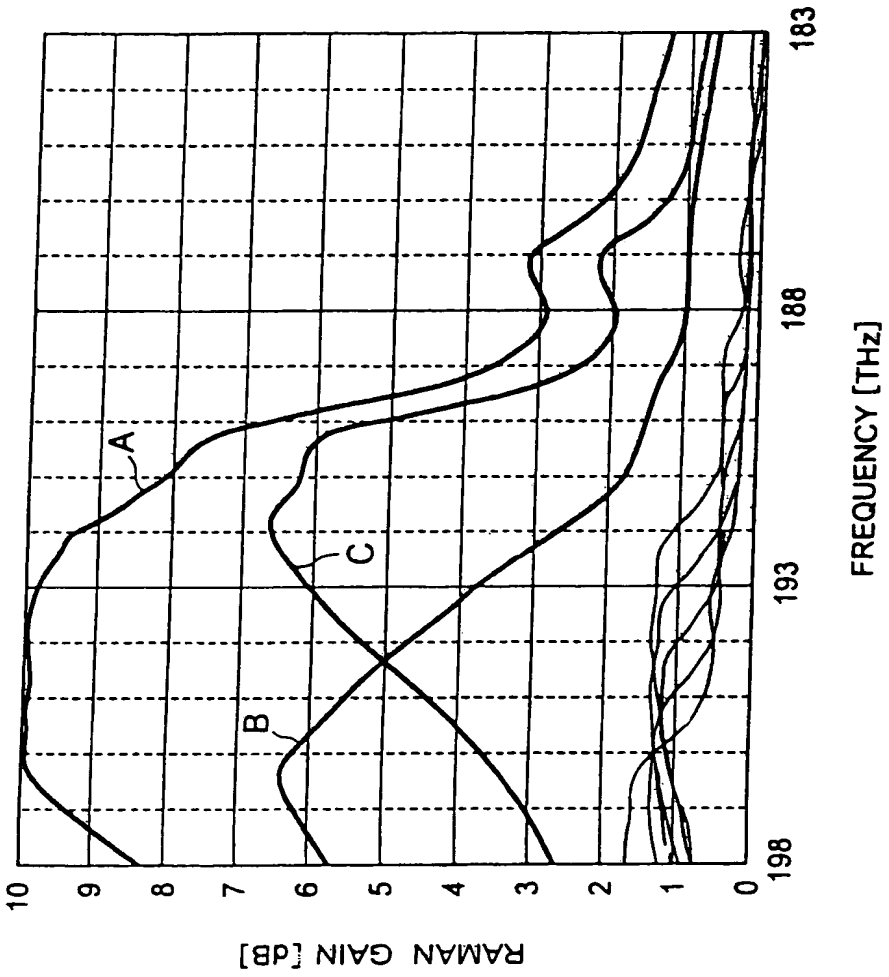

RAMAN GAIN [dB]
10
9
8
7
6
5
4
3
2
1
0
A
B
C
198
193
188
183
FREQUENCY [THz]

FIG. 20

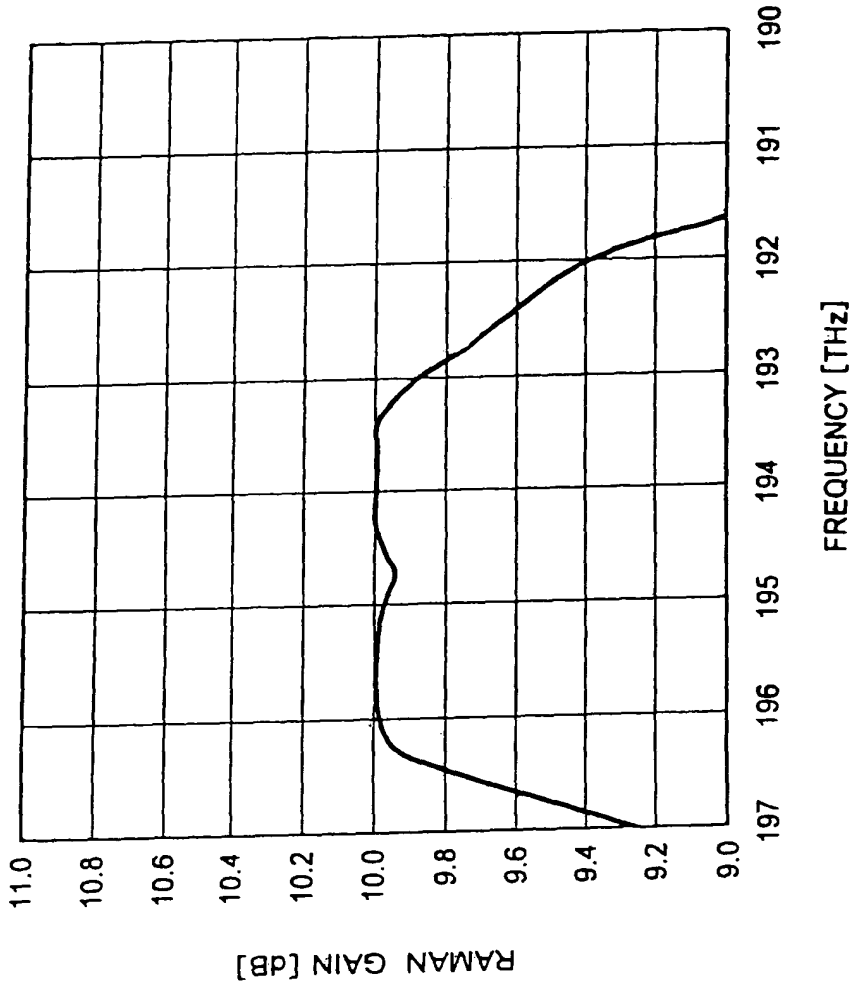

RAMAN GAIN [dB]
11.0
10.8
10.6
10.4
10.2
10.0
9.8
9.6
9.4
9.2
9.0
FREQUENCY [THz]
190
191
192
193
194
195
196
197

FIG. 21

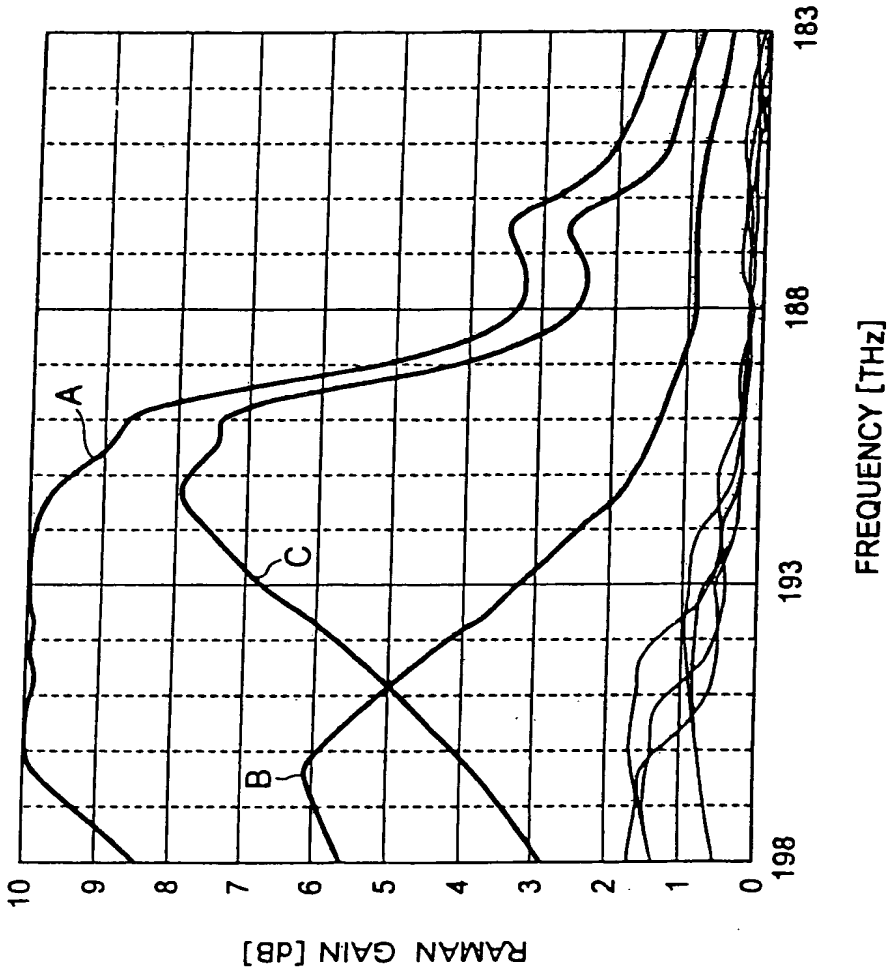

A
B
C
10
9
8
7
6
5
4
3
2
1
0
RAMAN GAIN [dB]
183
188
193
198
FREQUENCY [THz]

FIG. 22

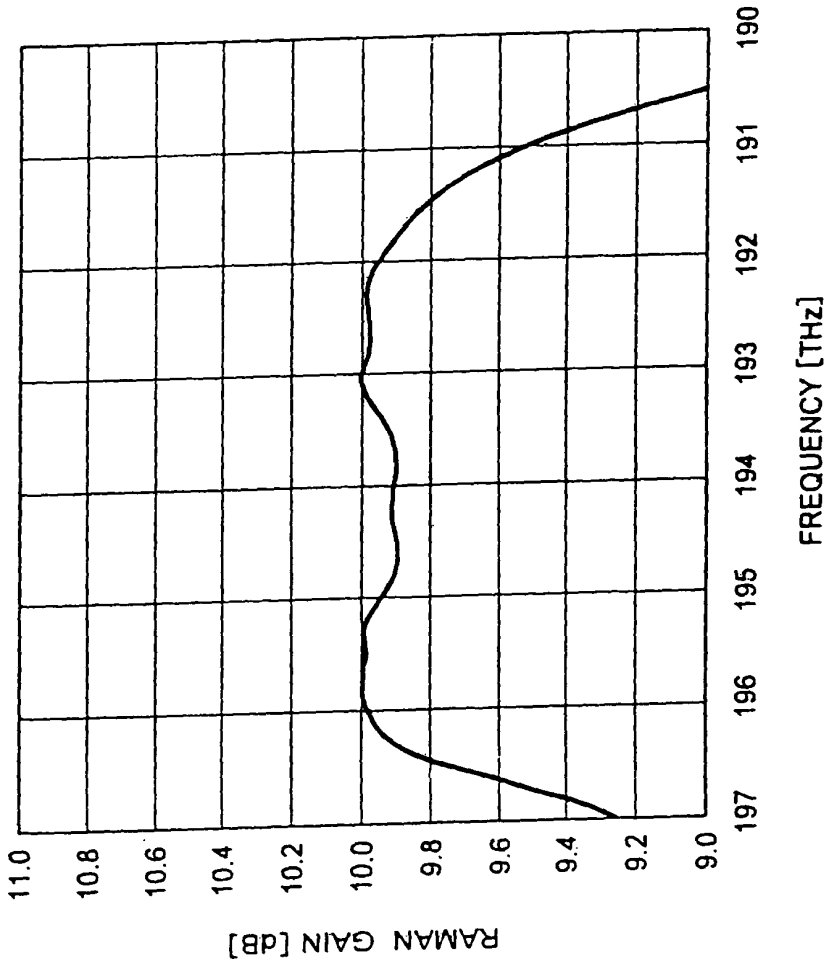

RAMAN GAIN [dB]
11.0
10.8
10.6
10.4
10.2
10.0
9.8
9.6
9.4
9.2
9.0
FREQUENCY [THz]
190
191
192
193
194
195
196
197

FIG. 23

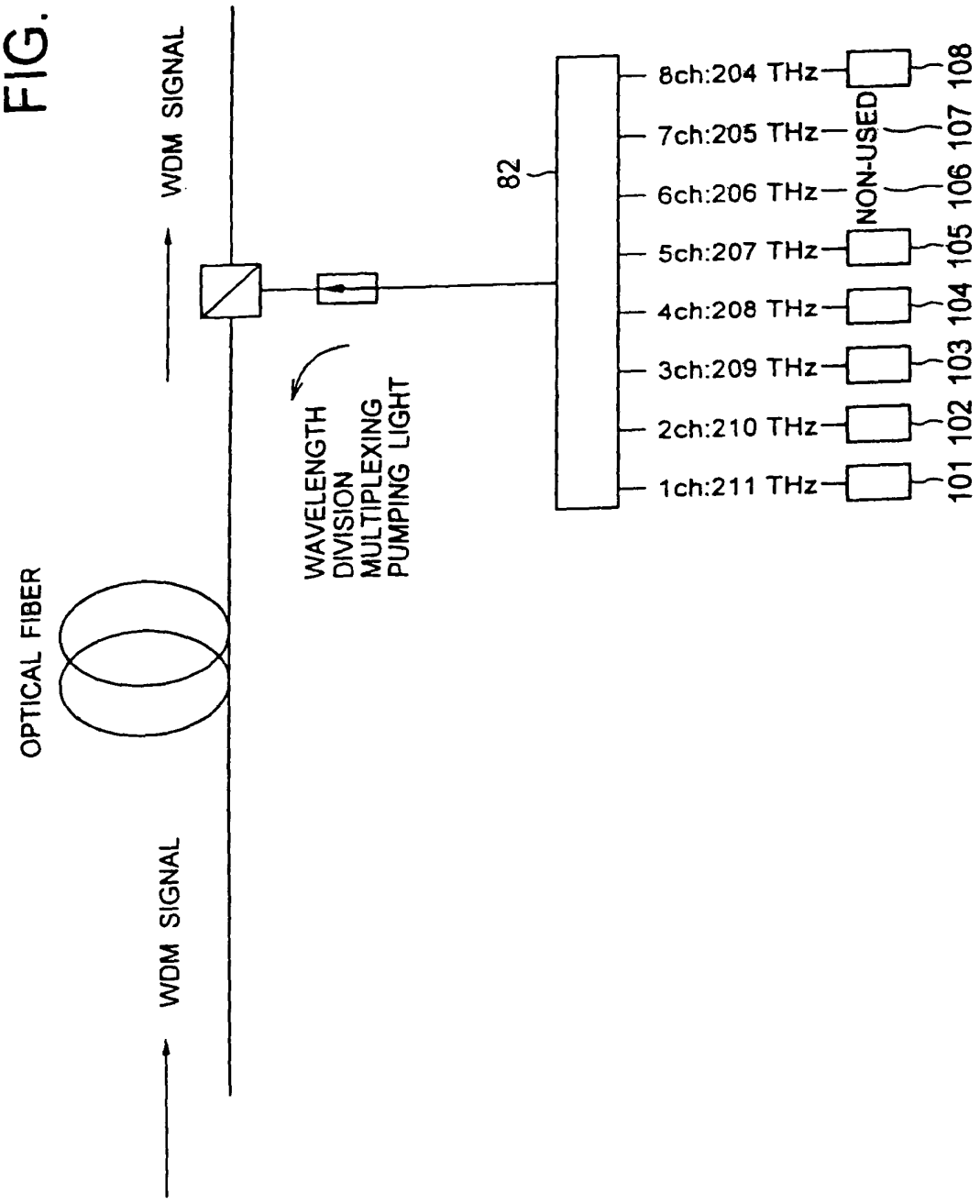

WDM SIGNAL
WDM SIGNAL
OPTICAL FIBER
WAVELENGTH DIVISION MULTIPLEXING PUMPING LIGHT
82
8ch:204 THz
7ch:205 THz
6ch:206 THz
5ch:207 THz
4ch:208 THz
3ch:209 THz
2ch:210 THz
1ch:211 THz
NON-USED
101 102 103 104 105 106 107 108

FIG. 24

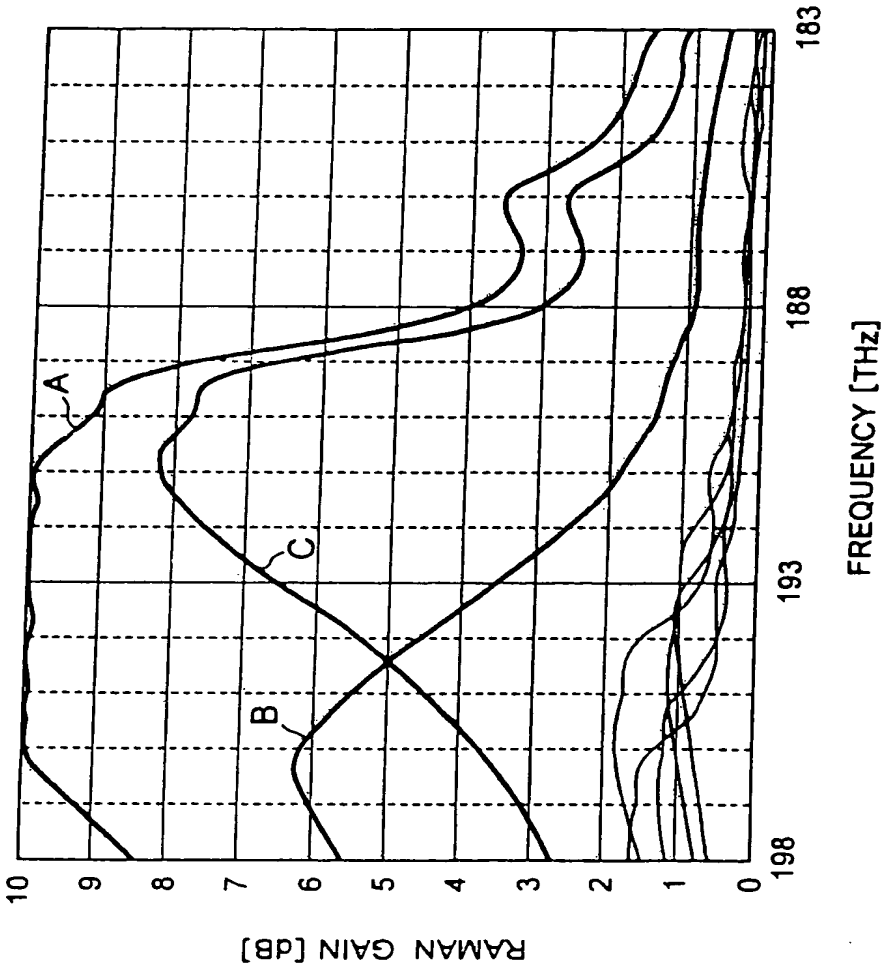

RAMAN GAIN [dB]
10
9
8
7
6
5
4
3
2
1
0
FREQUENCY [THz]
183
188
193
198
A
B
C

FIG. 25

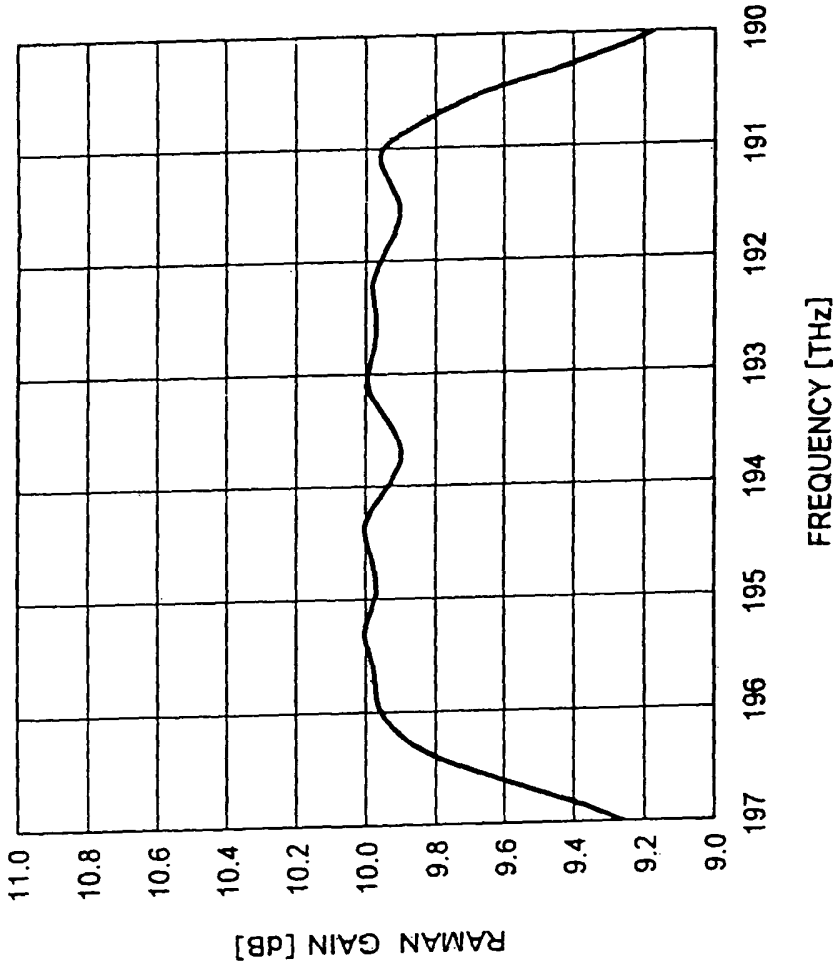

RAMAN GAIN [dB]
11.0
10.8
10.6
10.4
10.2
10.0
9.8
9.6
9.4
9.2
9.0
FREQUENCY [THz]
190
191
192
193
194
195
196
197

FIG. 26

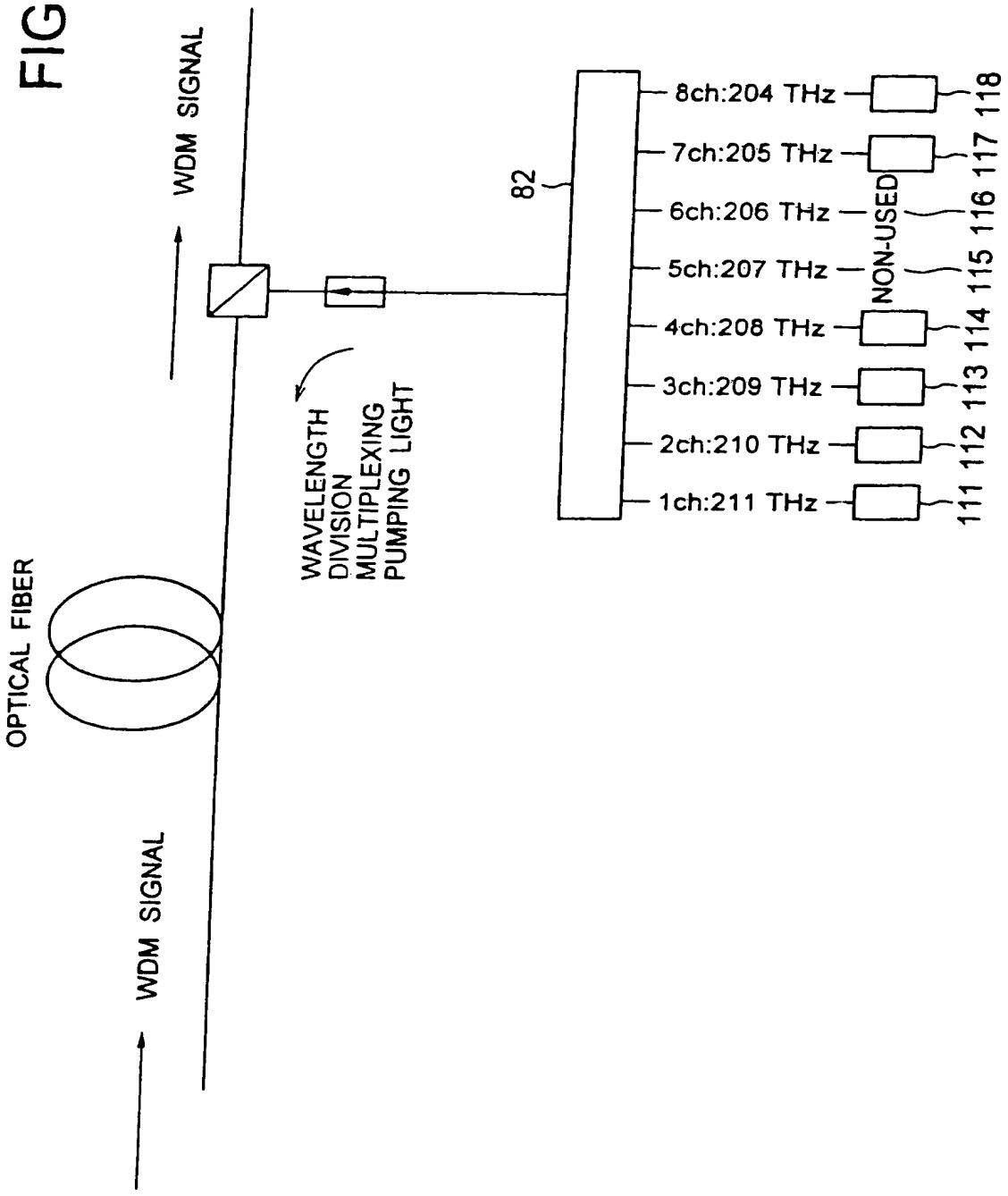

WDM SIGNAL
82
8ch:204 THz
7ch:205 THz
6ch:206 THz
5ch:207 THz
4ch:208 THz
3ch:209 THz
2ch:210 THz
1ch:211 THz
NON-USED
111 112 113 114 115 116 117 118
WAVELENGTH DIVISION MULTIPLEXING PUMPING LIGHT
OPTICAL FIBER
WDM SIGNAL

FIG. 27

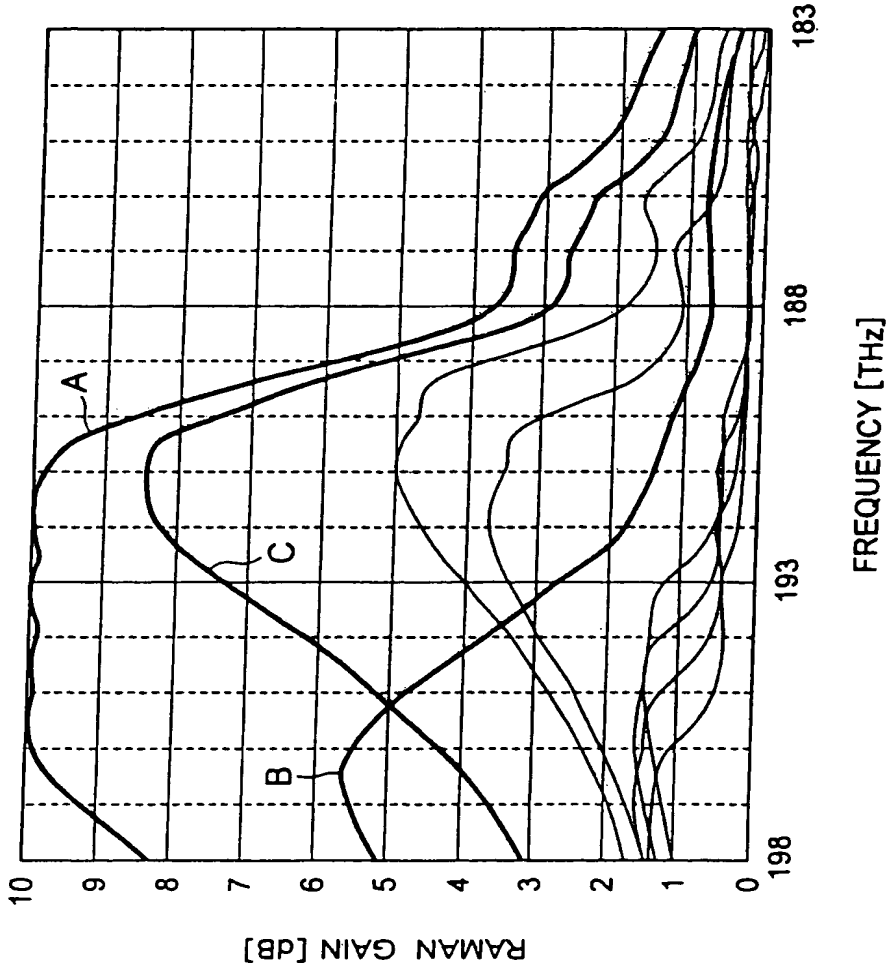

RAMAN GAIN [dB]
10
9
8
7
6
5
4
3
2
1
0
FREQUENCY [THz]
183
188
193
198
A
B
C

FIG. 28

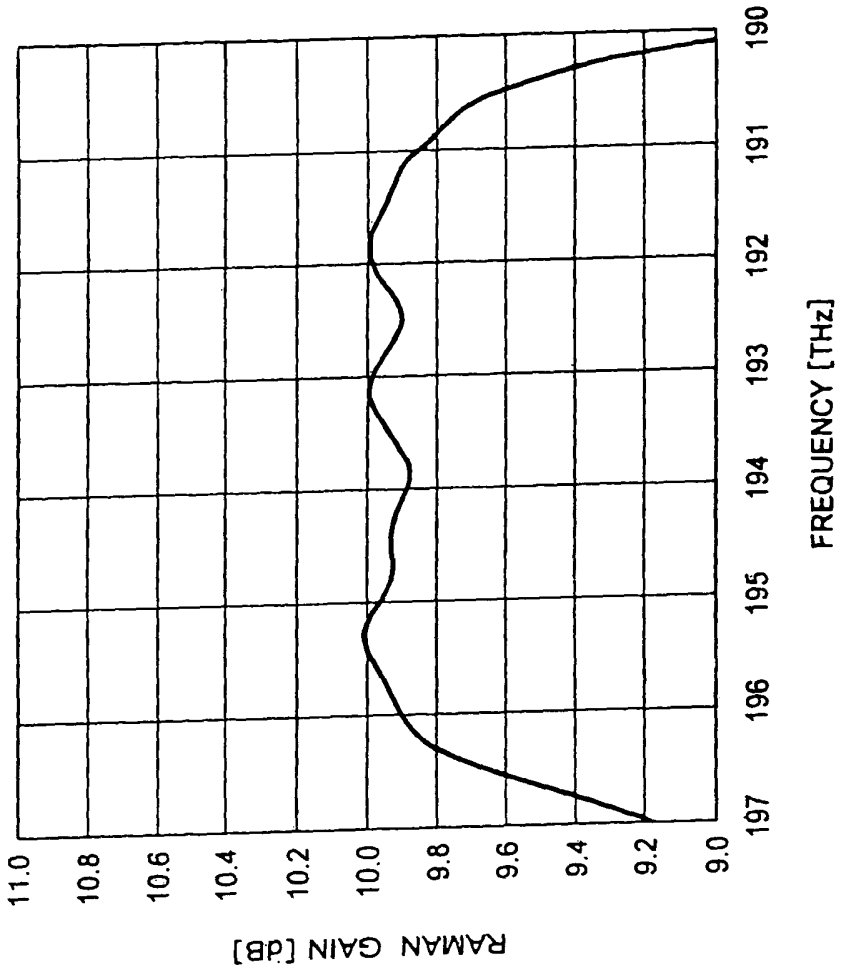

RAMAN GAIN [dB]
11.0
10.8
10.6
10.4
10.2
10.0
9.8
9.6
9.4
9.2
9.0
FREQUENCY [THz]
190
191
192
193
194
195
196
197

FIG. 29

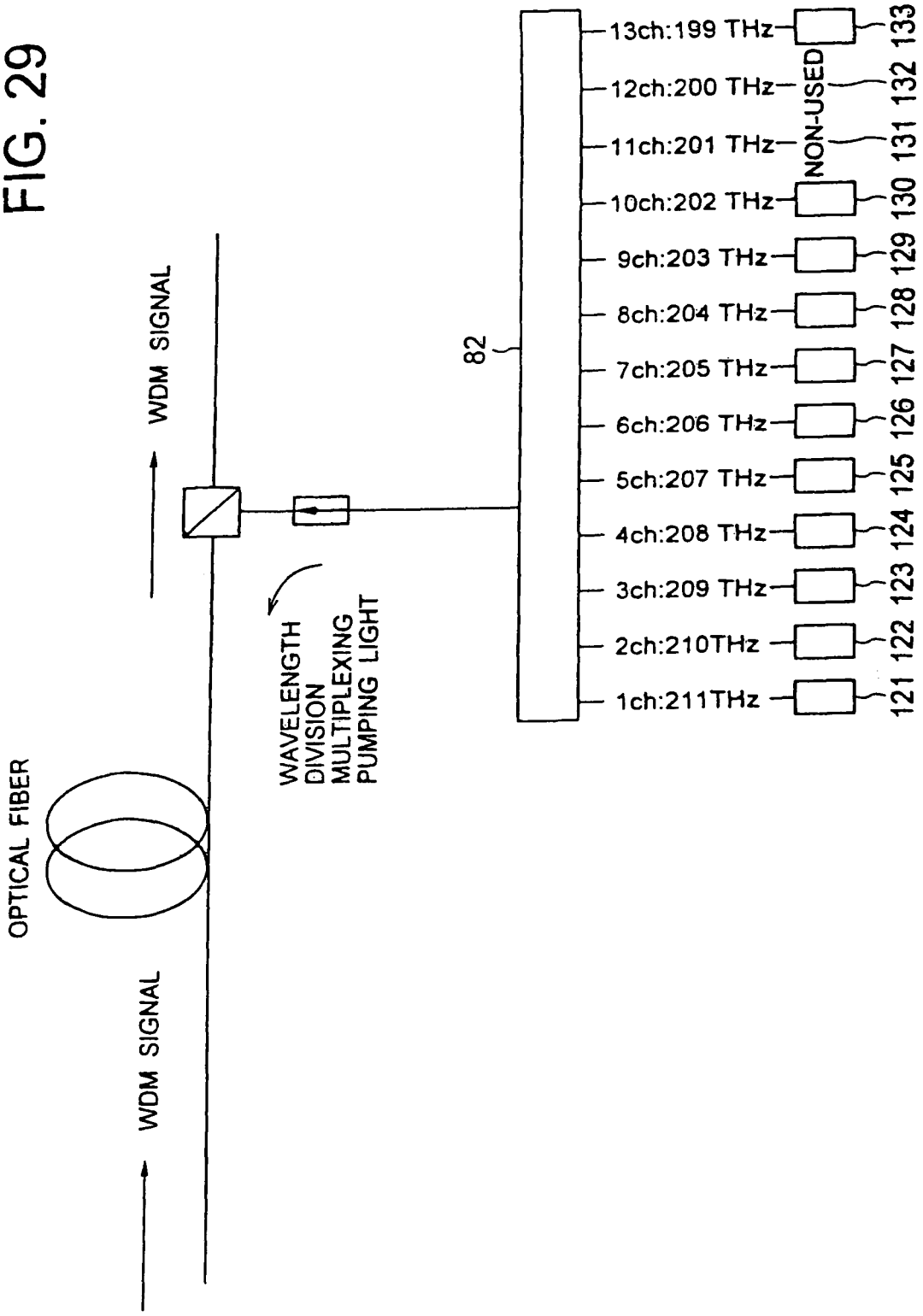

OPTICAL FIBER
WDM SIGNAL
WDM SIGNAL
WAVELENGTH DIVISION MULTIPLEXING PUMPING LIGHT
82
13ch:199 THz
12ch:200 THz
11ch:201 THz
10ch:202 THz
9ch:203 THz
8ch:204 THz
7ch:205 THz
6ch:206 THz
5ch:207 THz
4ch:208 THz
3ch:209 THz
2ch:210THz
1ch:211THz
NON-USED
133
132
131
130
129
128
127
126
125
124
123
122
121

FIG. 30

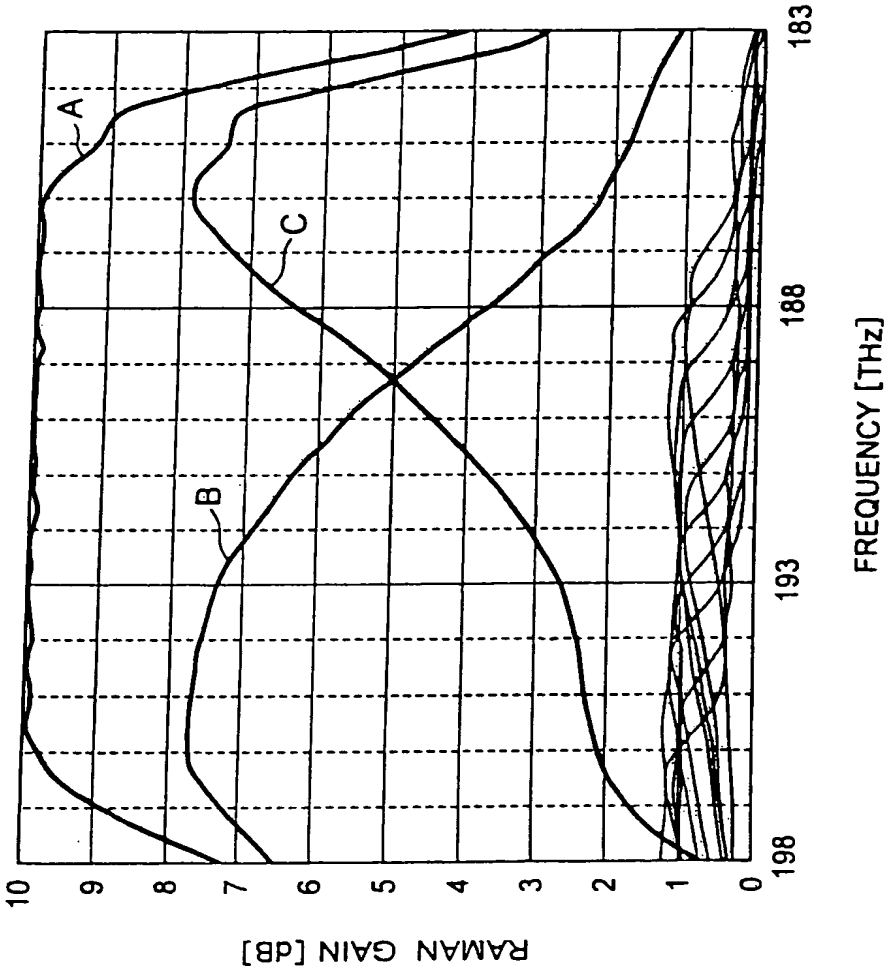

A
B
C
10
9
8
7
6
5
4
3
2
1
0
RAMAN GAIN [dB]
183
188
193
198
FREQUENCY [THz]

FIG. 31

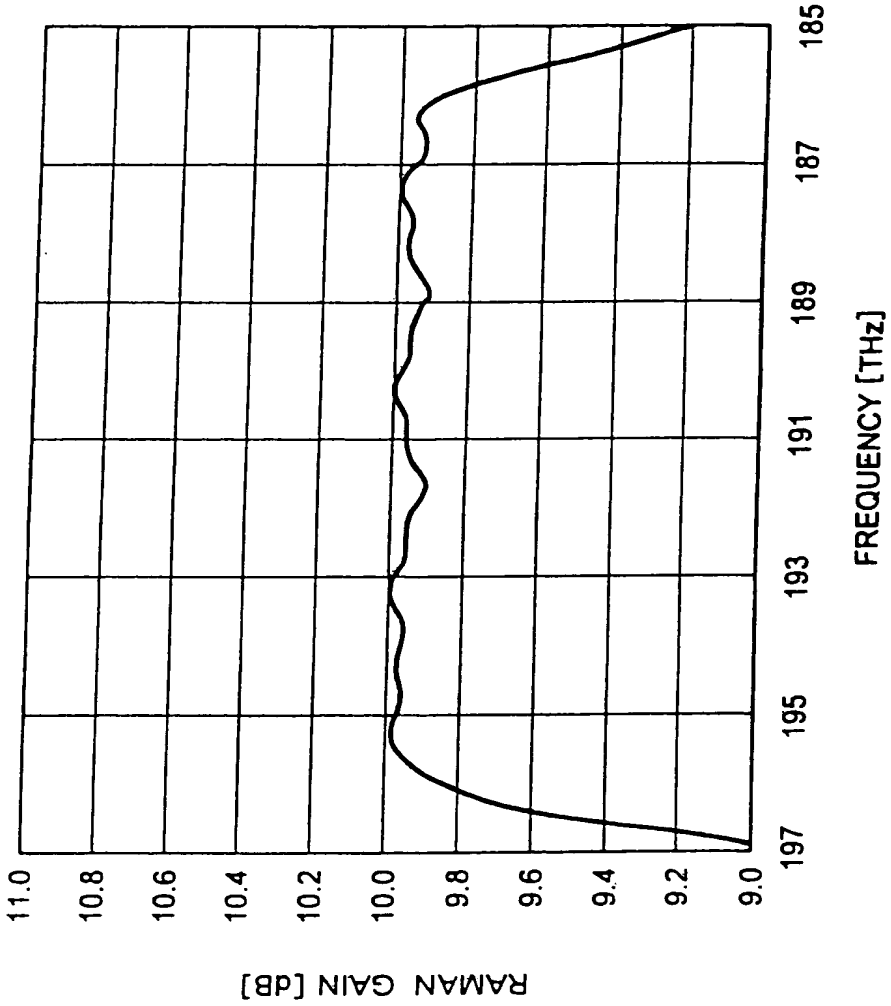

RAMAN GAIN [dB]
11.0
10.8
10.6
10.4
10.2
10.0
9.8
9.6
9.4
9.2
9.0
FREQUENCY [THz]
185
187
189
191
193
195
197

FIG. 32

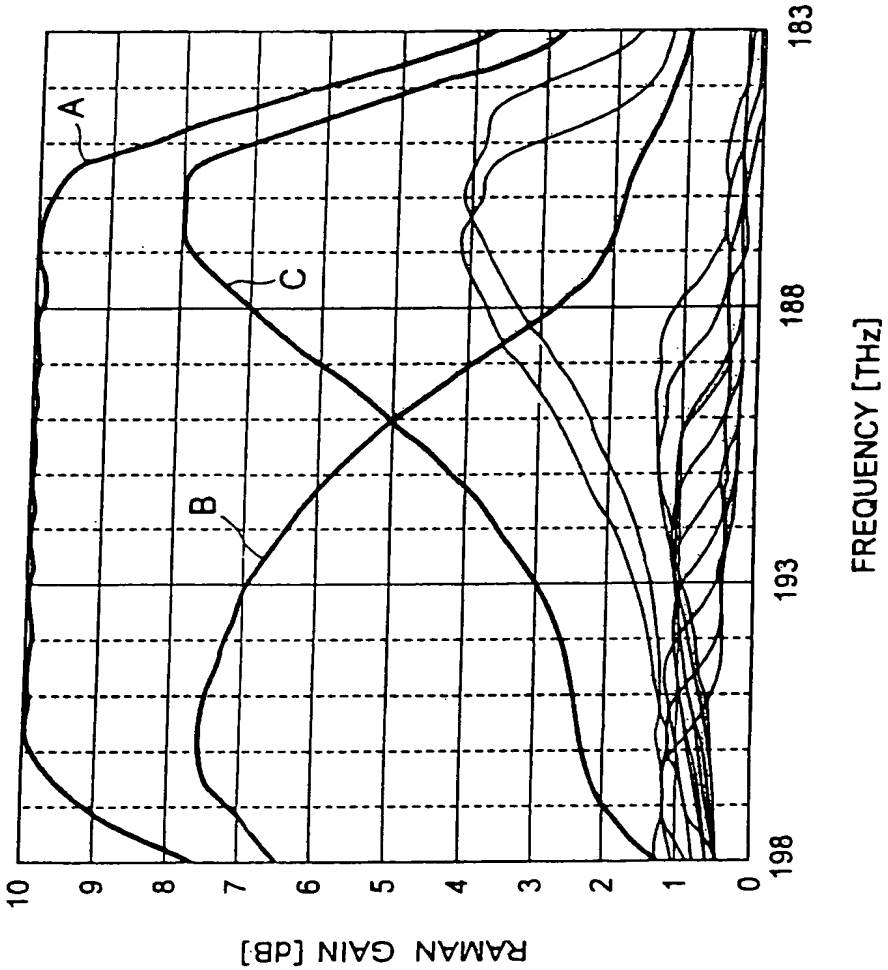

A
B
C
10
9
8
7
6
5
4
3
2
1
0
RAMAN GAIN [dB]
183
188
193
198
FREQUENCY [THz]

FIG. 33

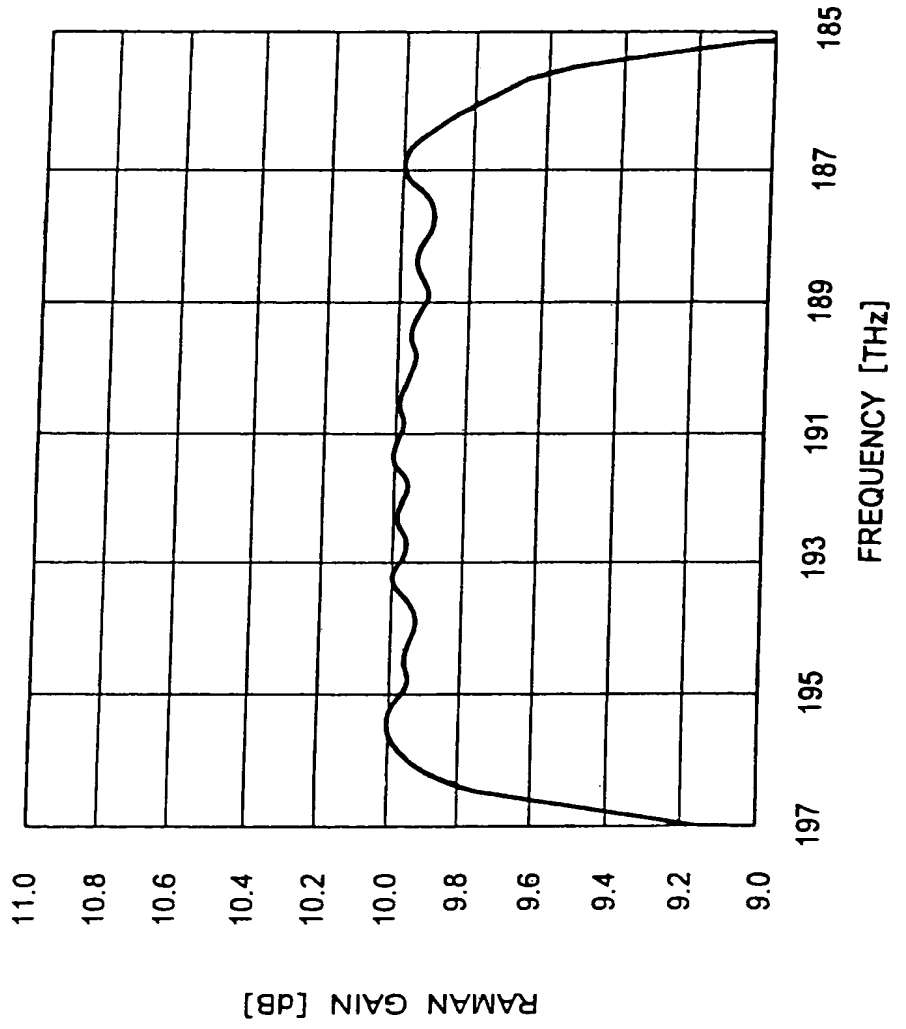

RAMAN GAIN [dB]
11.0
10.8
10.6
10.4
10.2
10.0
9.8
9.6
9.4
9.2
9.0
FREQUENCY [THz]
185
187
189
191
193
195
197

FIG. 34

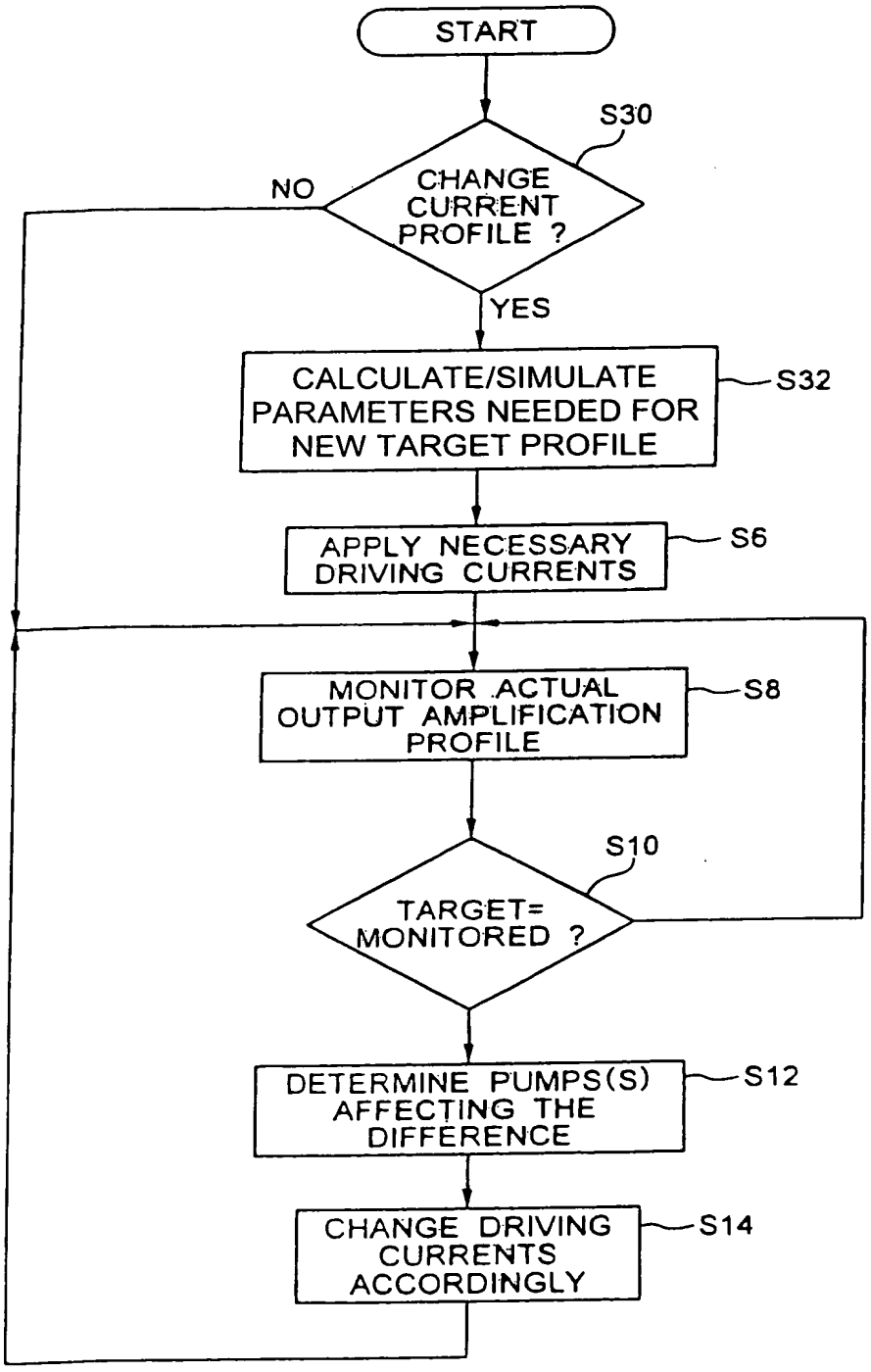
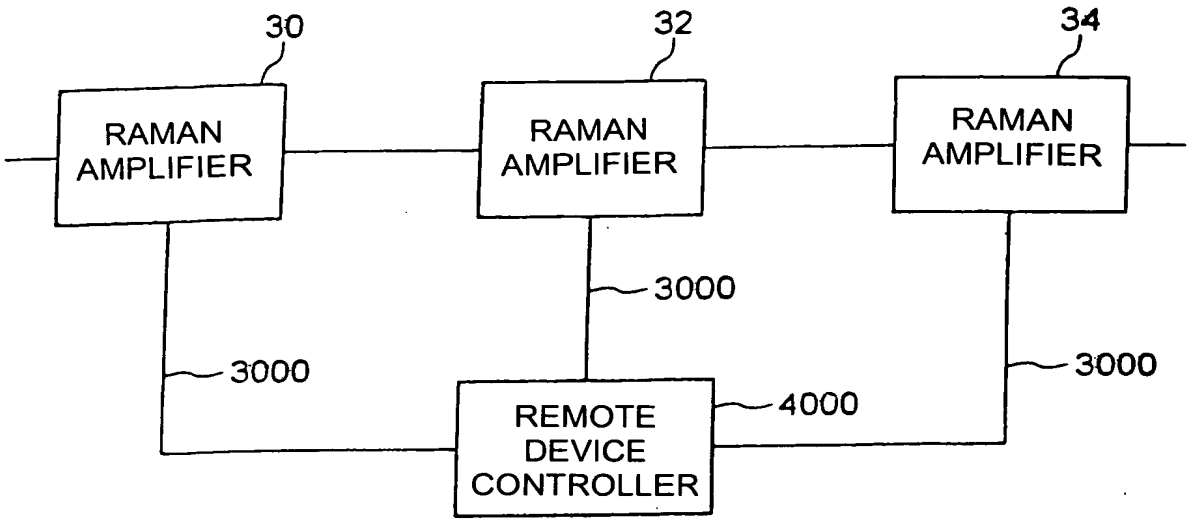

START
S30
CHANGE CURRENT PROFILE ?
NO
YES
CALCULATE/SIMULATE PARAMETERS NEEDED FOR NEW TARGET PROFILE
S32
APPLY NECESSARY DRIVING CURRENTS
S6
MONITOR ACTUAL OUTPUT AMPLIFICATION PROFILE
S8
S10
TARGET= MONITORED ?
DETERMINE PUMPS(S) AFFECTING THE DIFFERENCE
S12
CHANGE DRIVING CURRENTS ACCORDINGLY
S14

FIG. 35


30
32
34
RAMAN AMPLIFIER
RAMAN AMPLIFIER
RAMAN AMPLIFIER
3000
3000
3000
4000
REMOTE DEVICE CONTROLLER